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Title: Geothermal Resource Analysis at Tohatchi hot springs, New Mexico

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Geothermal Resource Analysis at Tohatchi Hot Springs, New Mexico

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Sam Woods, Suzanne Singer, Stanford Lake
Tosidoh Group

Objective

Improve the understanding of geothermal resource at Tohatchi Hot Springs, New Mexico using **exploratory data analysis** and **machine learning (ML) methods**

Methods and Approach

1. Analyze and process data from different data sources (including documents/reports provided by Tosidoh Group)
2. Perform advanced ML data analyses using geological, geophysical, and geochemical datasets (using LANL-developed/patented ML methods)
3. Characterize geothermal source and governing mechanisms that is making the water hot
   For example, identify which data attributes are important to understand the heat source

Deliverable

A report of the findings and recommendations based on our ML analyses (will be provided to the Tosidoh Group at the completion of the project)

Existing report

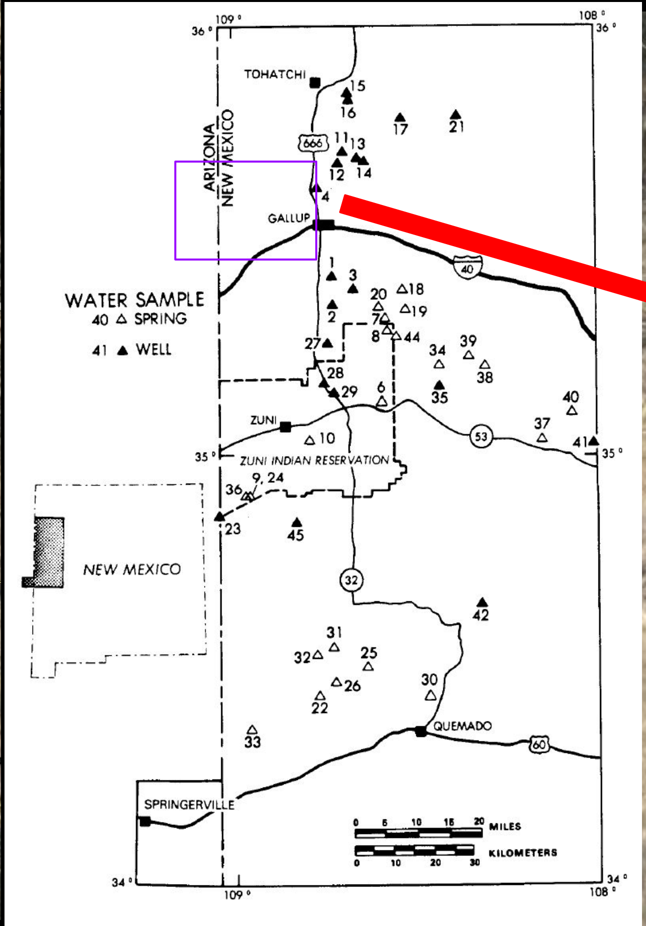
Geothermal potential of west-central New Mexico from geochemical and thermal gradient data

by

D. Levitte and D.T. Gambill (1980)

Study Area


Tohatchi
Nazlini
Navajo
Kinlichee
Fort Defiance
Window Rock
St Michaels
Yah-Ta-Hey
Gallup
Fort Wir
Wide Ruin
Lupton
Houck
Vanderwagen
Sanders
Zuni Reservation
ZUNI RESERVATION
Fence Lake
St Johns
Red Hill
Springerville


109°
108°
36°
35°
34°
TOHATCHI
ARIZONA
NEW MEXICO
666
GALLUP
40
WATER SAMPLE
40 △ SPRING
41 ▲ WELL
ZUNI
ZUNI INDIAN RESERVATION
53
32
NEW MEXICO
QUEMADO
60
SPRINGERVILLE
0 5 10 15 20 MILES
0 10 20 30 KILOMETERS


Tohatchi High School
Temporarily closed
Tohatchi
Mustang Convenience Store
491
491

Data Summary (based on Report Review)

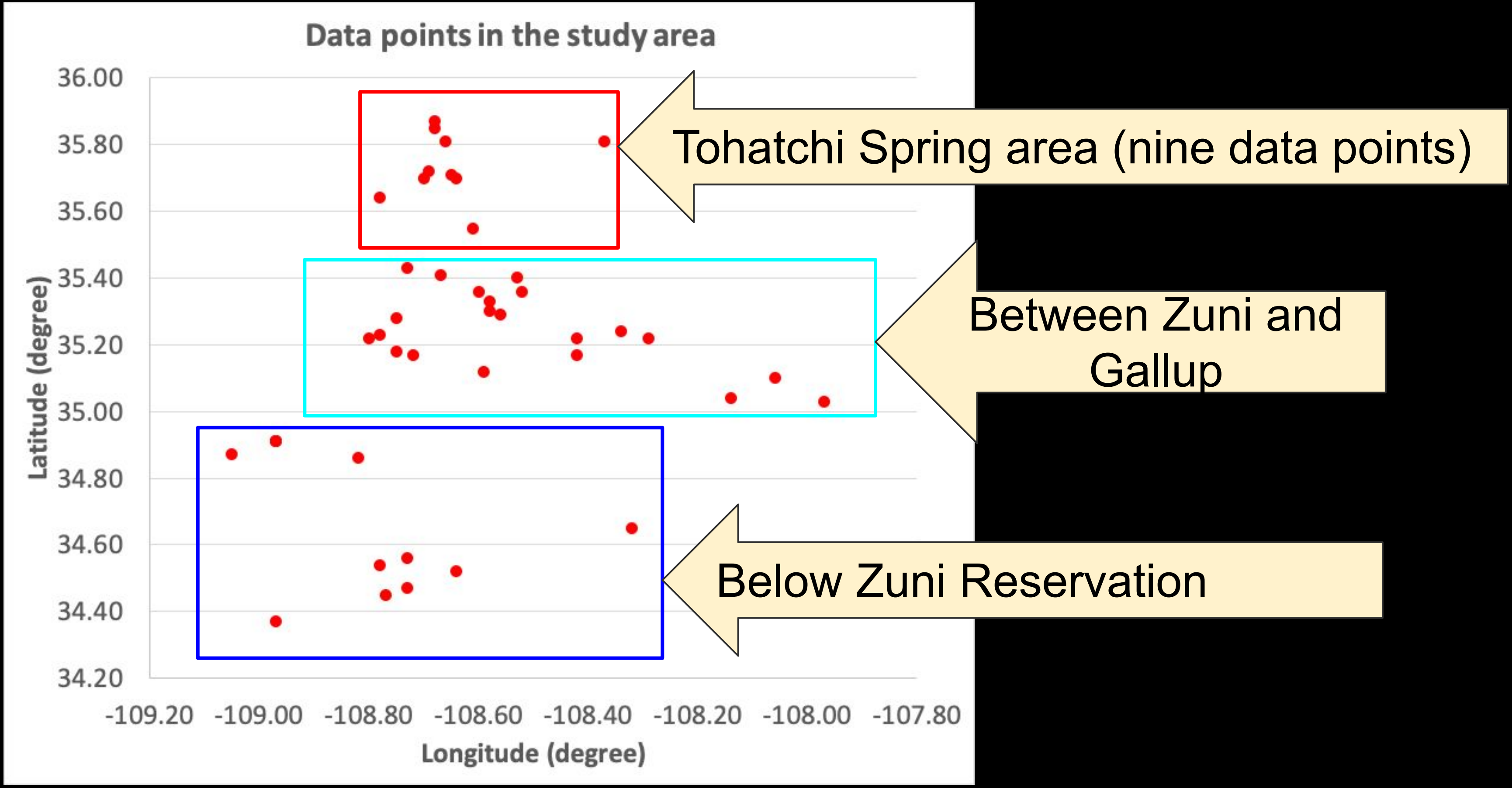
1. **Geochemistry** data (at 43 wells)
   pH, flow rate (missing values), major anions/cations, rock types

   SiO_2, Fe, Mn, Ca, Mg, Na, K, Ba, Sr, B, Li, HCO_3, SO_4, Cl, F

2. **Geothermometry** data (at 43 wells)
   Quartz water vapor, Na-K-Ca

3. **Geothermal gradient** (at 29 wells)

Study Area


Data points in the study area
36.00
35.80
35.60
35.40
35.20
35.00
34.80
34.60
34.40
34.20
Latitude (degree)
-109.20
-109.00
-108.80
-108.60
-108.40
-108.20
-108.00
-107.80
Longitude (degree)
Tohatchi Spring area (nine data points)
Between Zuni and Gallup
Below Zuni Reservation

Report Review: Hydrogeology

- Basaltic flows range between 27 Myr to 700 Myr
- Zuni uplift ranges between 29 to 48 km and has several northwest-trending faults
- No defined recharge areas and ground water flow directions
- Permeability is controlled by fractures and faults rather than rock (matrix) porosity and permeability
- Demonstrated by huge difference in water production among different wells/springs
- Warm springs are DL-9 and DL-24 or Rainbow and Sacred Springs with temperature of 22 and 21ºC, respectively
- Warm springs are within 0.8 km at the Zuni Indian Reservation

Report Review: Hydrogeology

- Based on chemistry, water is meteoric
- Zuni Indian Reservation has a maximum geothermal gradient of 67ºC/km
- The report suggests that the geothermal gradient is not hydrologically controlled
- East of Springerville, Arizona, the maximum geothermal gradients are between 76 to 138ºC/km
- But the report also suggests that high geothermal gradients are possibly due to a magmatic water at depth reaching to the ground surface

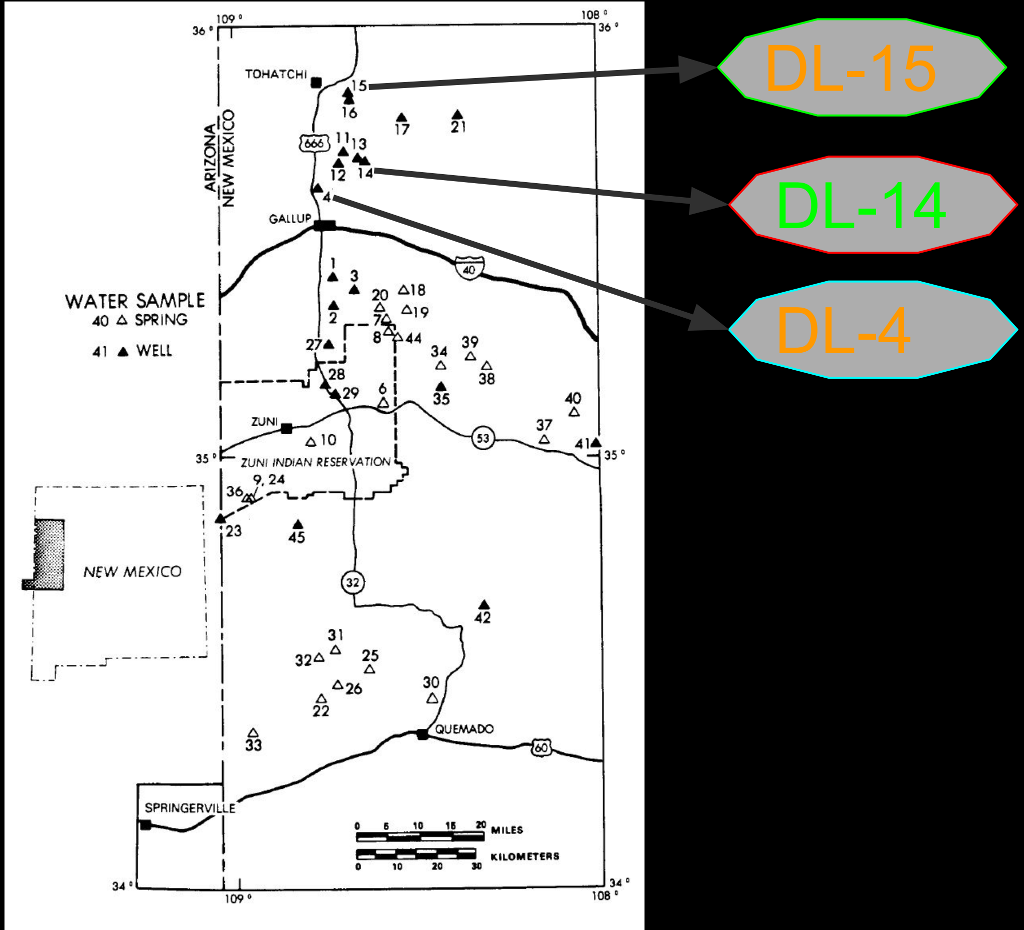
Report Review: Hydrogeology

Two hypotheses:

1. **Groundwater circulates from a shallow depth (~400 m)**
   (e.g., shallow geothermal system, secondary fracture permeability effects)
2. **Groundwater circulates from a greater depth**
   (e.g., deep circulation of water, forced-convection geothermal systems)

- However, the geothermal gradient is low 22ºC/km
- The low gradient does not suggest deep circulation
- The low gradient supports the first hypothesis

Study Area



TOHATCHI
GALLUP
ZUNI
QUEMADO
SPRINGERVILLE
ARIZONA
NEW MEXICO
ZUNI INDIAN RESERVATION
WATER SAMPLE
40 △ SPRING
41 ▲ WELL
NEW MEXICO
MILES
KILOMETERS
DL-15
DL-14
DL-4

Tohatchi Hydrogeology

- **DL-14** is an artesian well drilled at 649 m depth; Temperature is 16.5ºC
- Huge recharge area surrounding this well might be the cause of low temperature groundwater
- **DL-4** has higher temperature/gradient (T=45ºC, 91ºC/km) than other wells in the vicinity
- This supports the second hypothesis
- However, water type is meteoric not connate or true thermal
- The report also describes that "the source of **DL-4** and **DL-15** waters are from deep but boron and lithium ratios are low; therefore, water are meteoric"

This is a conundrum! We hope to resolve it using our ML analyses!

Report Review: Geothermal

1. Possible low-temperature geothermal reservoir between Gallup and Tohatchi below **Chinle**
2. Springerville has high temperature gradient and possibly by circulation from depth or may be from shallow uranium deposits

   (for more, please see a report by Arizona Bureau of Geology and Mineral Technology, 1980)
3. Based on existing data, Zuni Reservation may not be forecasted as a potential geothermal reservoir

Conclusions and Next Steps

- Gallup-Tohatchi, Springerville, and Zuni Indian Reservation areas appear to be suitable for further exploration of hot dry rock (HDR) geothermal resources
- Require more geothermal gradient and water chemistry data for a robust analyses prediction

Next steps: Digitize, digest, and analyze the existing data using machine learning

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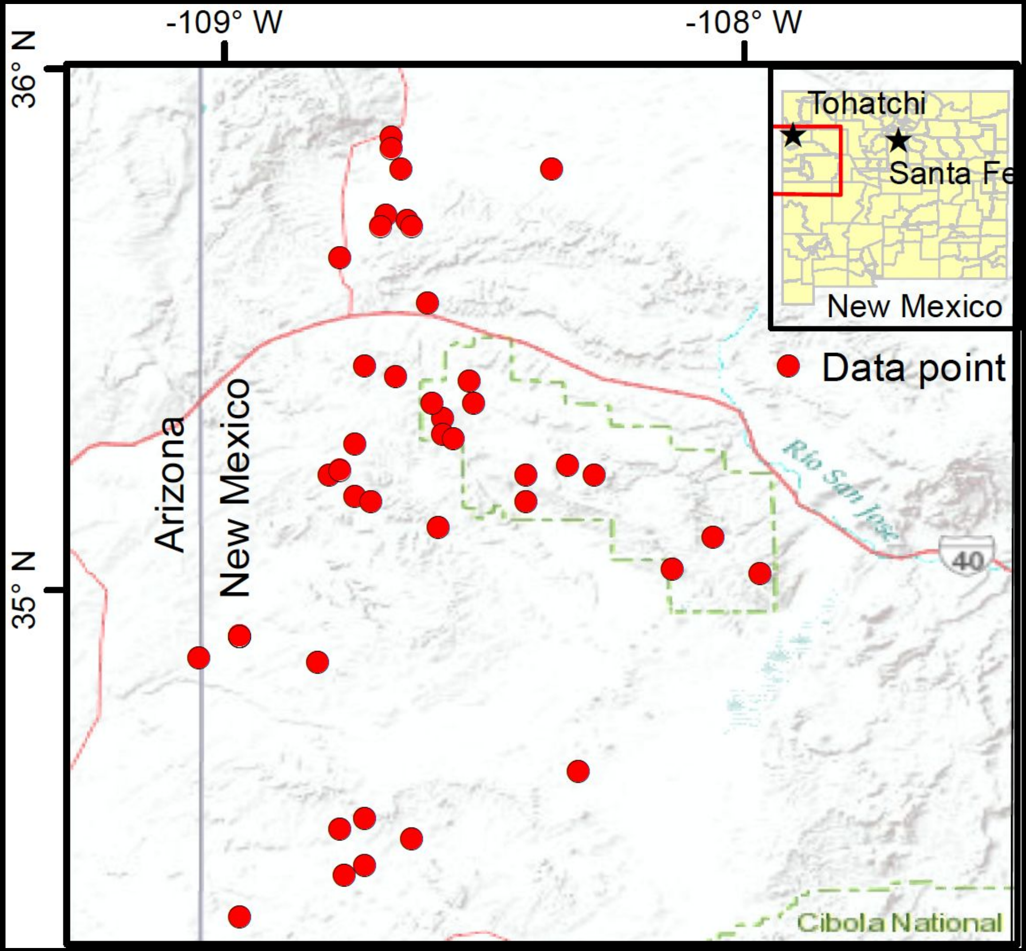
Recap

Hypotheses:

1. Groundwater circulates from a shallow depth (~400 m) (e.g., shallow geothermal system, secondary fracture permeability effects)
2. Groundwater circulates from a greater depth (e.g., deep circulation of water, forced-convection geothermal systems)

Recap



- Reviewed a LANL geothermal report (Levitte and Gambill 1980)
- Gallup-Tohatchi, Springerville, and Zuni Indian Reservation areas appear to be suitable for further exploration of hot dry rock (HDR) geothermal resources
- Require more geothermal gradient and water chemistry data for a robust analyses prediction

Key Questions **(defined by Tosidoh Group)**

1. Why is water hot?
2. What kind of geothermal technology is appropriate in this area?
3. Can we use it for generating H_2, heating, and build a greenhouse system?
4. How big is the reservoir?
5. How much water is there?
6. Will it finish up or is it sustainable for long-term production?

Key Questions/Answers

1. Why is water hot? hot magma at depth
2. What kind of geothermal technology is appropriate in this area? various
3. Can we use it for generating H_2, heating, and build a greenhouse system? Yes
4. How big is the reservoir? Will explain in later slides
5. How much water is there? Will explain in later slides
6. Will it finish up? Will explain in later slides

How can we utilize the hot water?

1. Generating H_2?
2. Domestic/space heating?
3. Heating greenhouse system for agriculture?
4. Power generation?
5. Spa industry?

Geothermal Facilities in NM

Agriculture/Greenhouse	5
Domestic/Space heating	3
Transportation/Producing H_2	0
Electricity/Power plant	1
Entertainment/Spa	14

Possible Geothermal Facilities

Facility	Yes/No
Agriculture/greenhouse	√ **Y**
Domestic/space heating	√ **Y**
Transportation/H_2 extraction	√ **Y**
Spa	√ **Y**
Power plant	X No

How Big is the Reservoir?

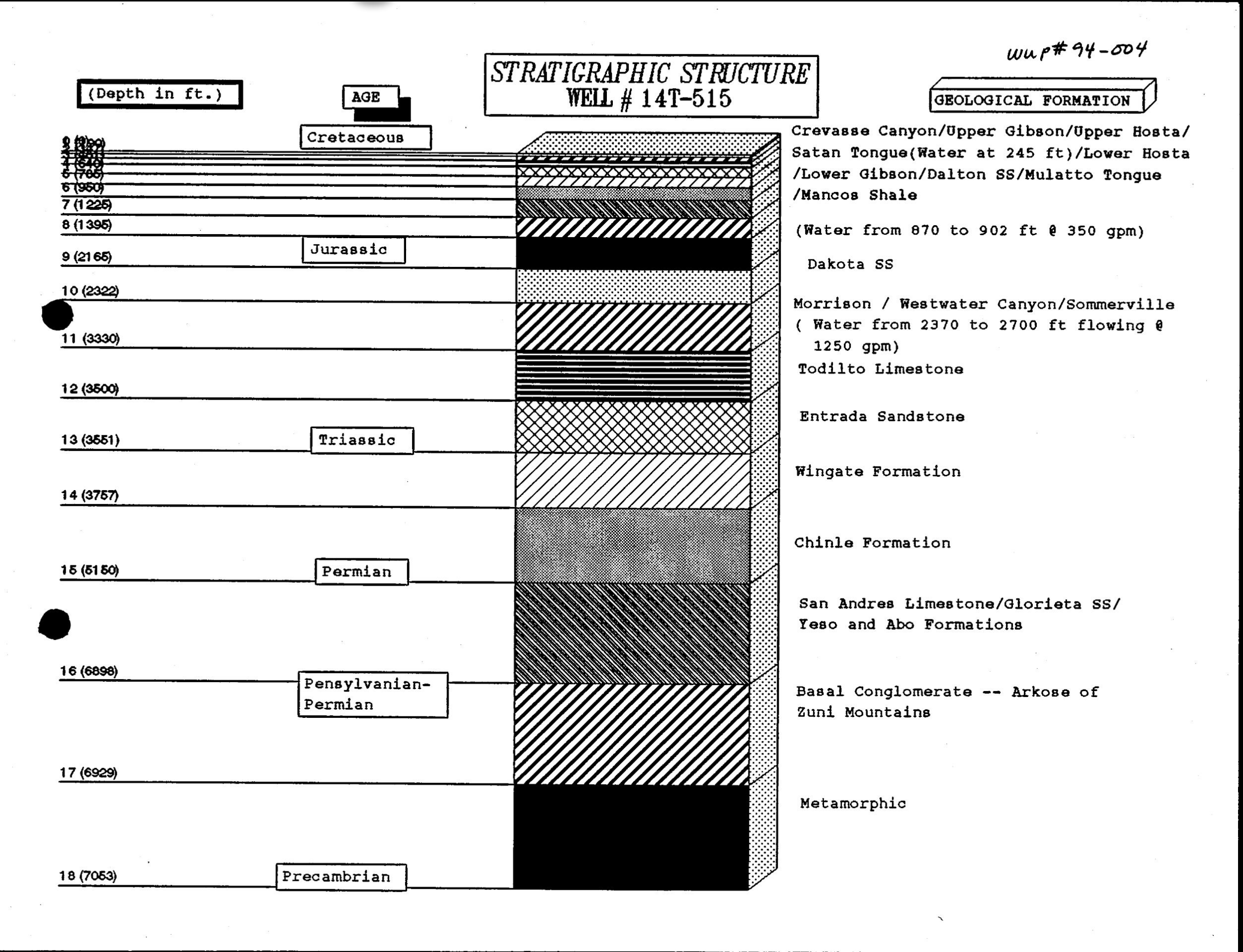
Well 14T-515 (drilled in 1954) is located at 5 mile NE of Tohatchi
Lat: 355304 Long: 1084006
Screen: Not known

Water Temperature: 37 ºC
pH 8.41
Flow 508 gpm
Specific Conductivity 655 S/micro-meter (?)

Total Reservoir Area: 31.97 sq. Miles

In 1966, 25c per 1,000 gallons for surface water while 30c per 1000 gallons for well water

How Big is the Reservoir?



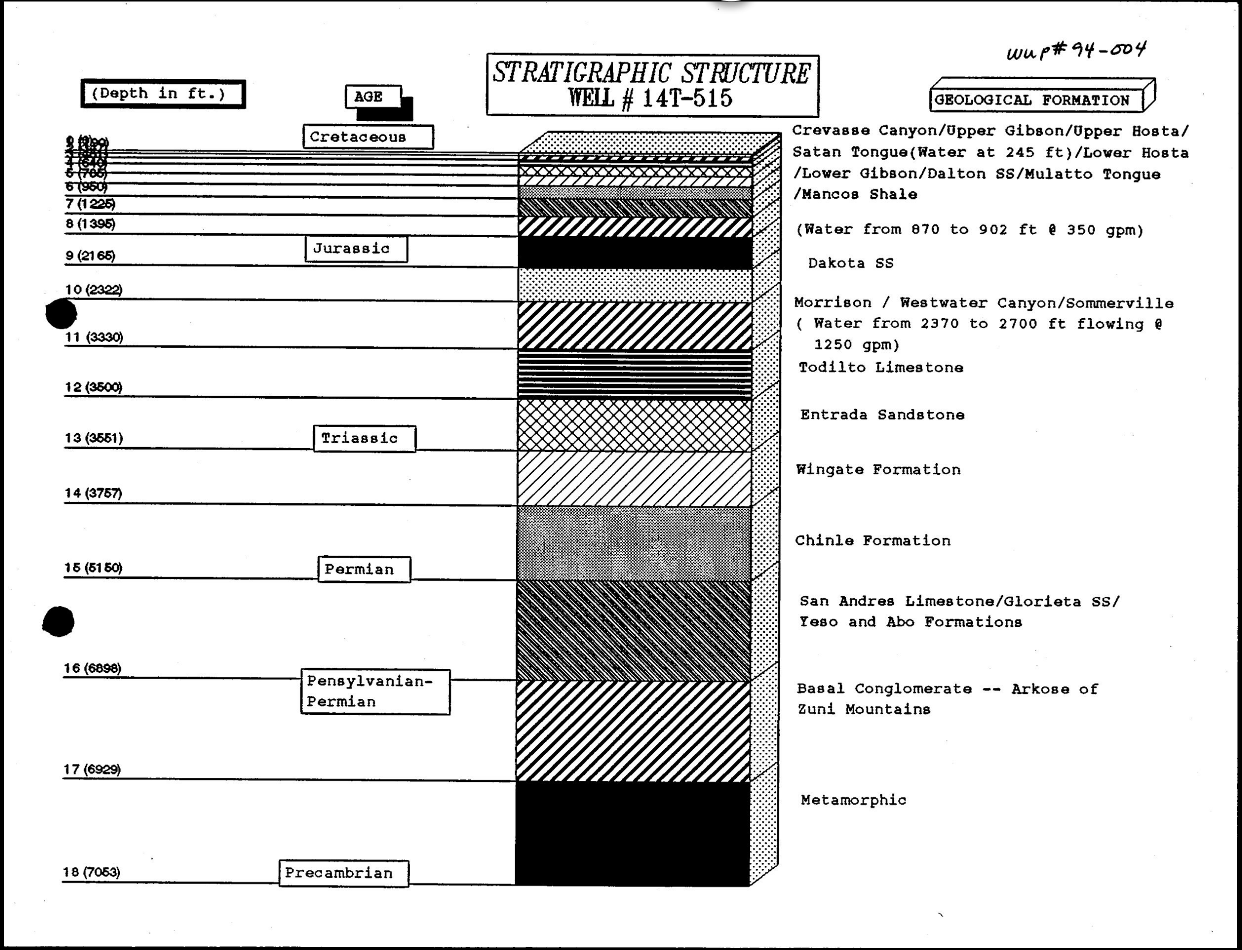
Well Record

Depth start - end (ft)	Formation	Aquifer
0 - 190	Crevasse Canyon	Upper Gibson Coal Member
190 - 347	,,	Upper Hosta SS Tonge
347 - 451	,,	Satan Tongue of Mancos
451 - 640	,,	Lower Hosta Tongue SS
640 - 785	,,	Lower Gibson Coal Member
785 - 950	**,,**	**Dalton Sandstone Member**
950 - 1225	,,	Malato Tongue of Mancos
1225 - 1395	Gallup Sandstone	,,
1395 - 2165	Mancos Shale	,,
2165 - 2322	Dakota Sandstone	,,

Well Record

Depth start - end (ft)	Formation	Aquifer
2322 - 3330	Morrison Formation	Westwater Canyon Member
3330 - 3500	,,	Todilto Limestone
3500 - 3551	,,	Entrada Sandstone
3551 - 3757	Wingate Formation	
3757 - 5150	Chinle Formation	
5150 - 6898	Permian System	
6898 - 6929	Penn-Perm System	
6829 - 7053	PreC-Metamorphics	

How Big is the Reservoir?



First Aquifer

Aquifer unit 8
Mostly shale
Depth 870 - 902 ft
Thickness: 32 ft
Flowrate: 350 gpm

Second Aquifer

Aquifer unit 11
Morrison Formation
(sandstone and shale)
Depth: 2,370 - 2,700 ft
Thickness: 330 ft
Flowrate: 1,250 gpm

Conclusions

Hypotheses:

1. Groundwater circulates from a shallow depth (~400 m) (e.g., shallow geothermal system, secondary fracture permeability effects)
2. Groundwater circulates from a greater depth (e.g., deep circulation of water, forced-convection geothermal systems)

- Low geothermal gradient supports the first hypothesis
- Also, this is a mostly porous system (not fractured)
- Combination of preceding two factors makes this a sustainable system for long-term production without requiring to build a special system to bring resources to the surface

Conclusions

- Information that we do not have: porosity, recharge area, and recharge rate
- Above information would help us to provide a better estimation
- However, based on aquifer thickness and reservoir area, we can say that it is a substantially large aquifer / reservoir

1. How big is the reservoir? It is substantially large for long-term production
2. How much water is there? Aquifer storage is substantial
3. Will it finish up? Most probably no; still aquifer recharge rates are unknown

Future Work

- Generate temperature and heat flow contours
- Reserve estimation using standard porosity for sandstone, shale, and limestone
- Develop a preliminary prospectivity map based on the available information showing potential locations for geothermal exploration / production

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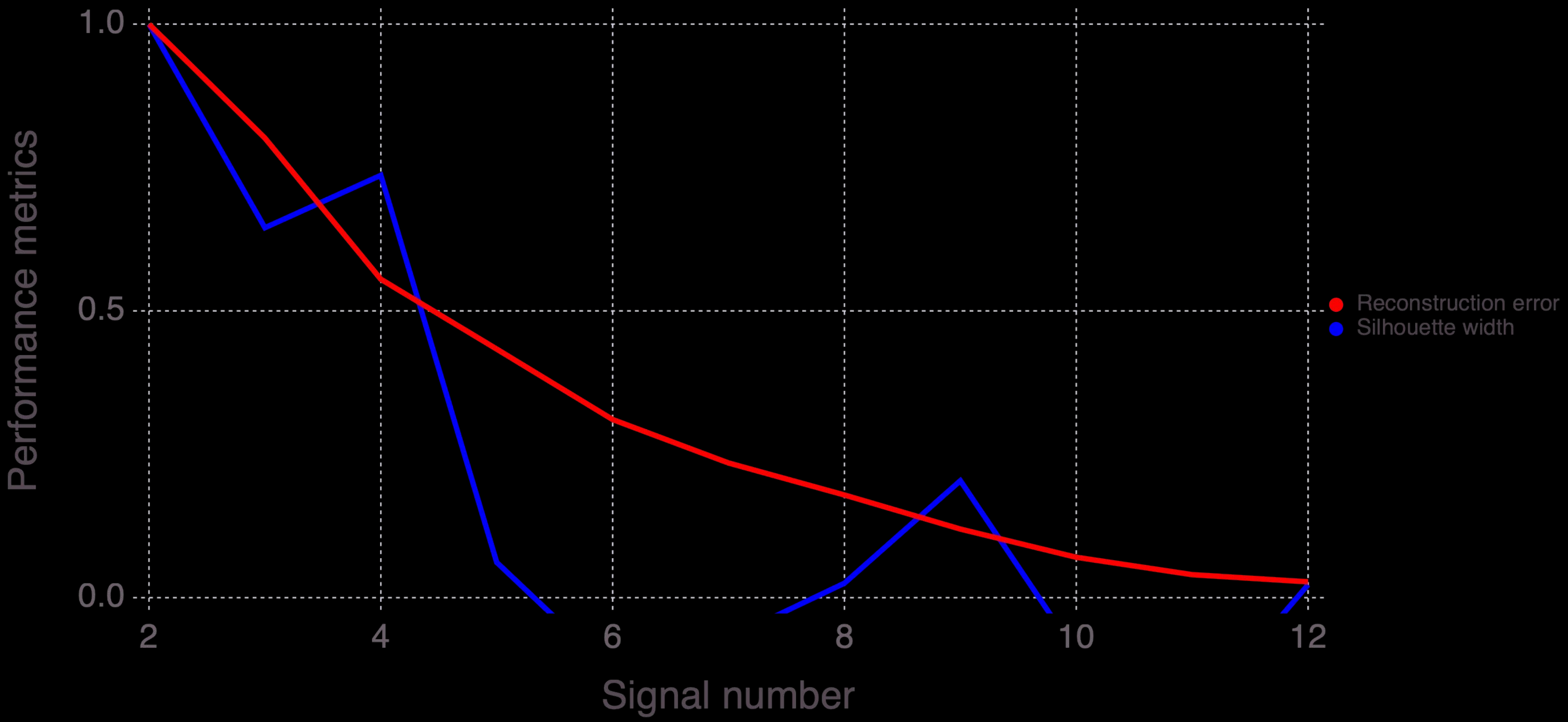
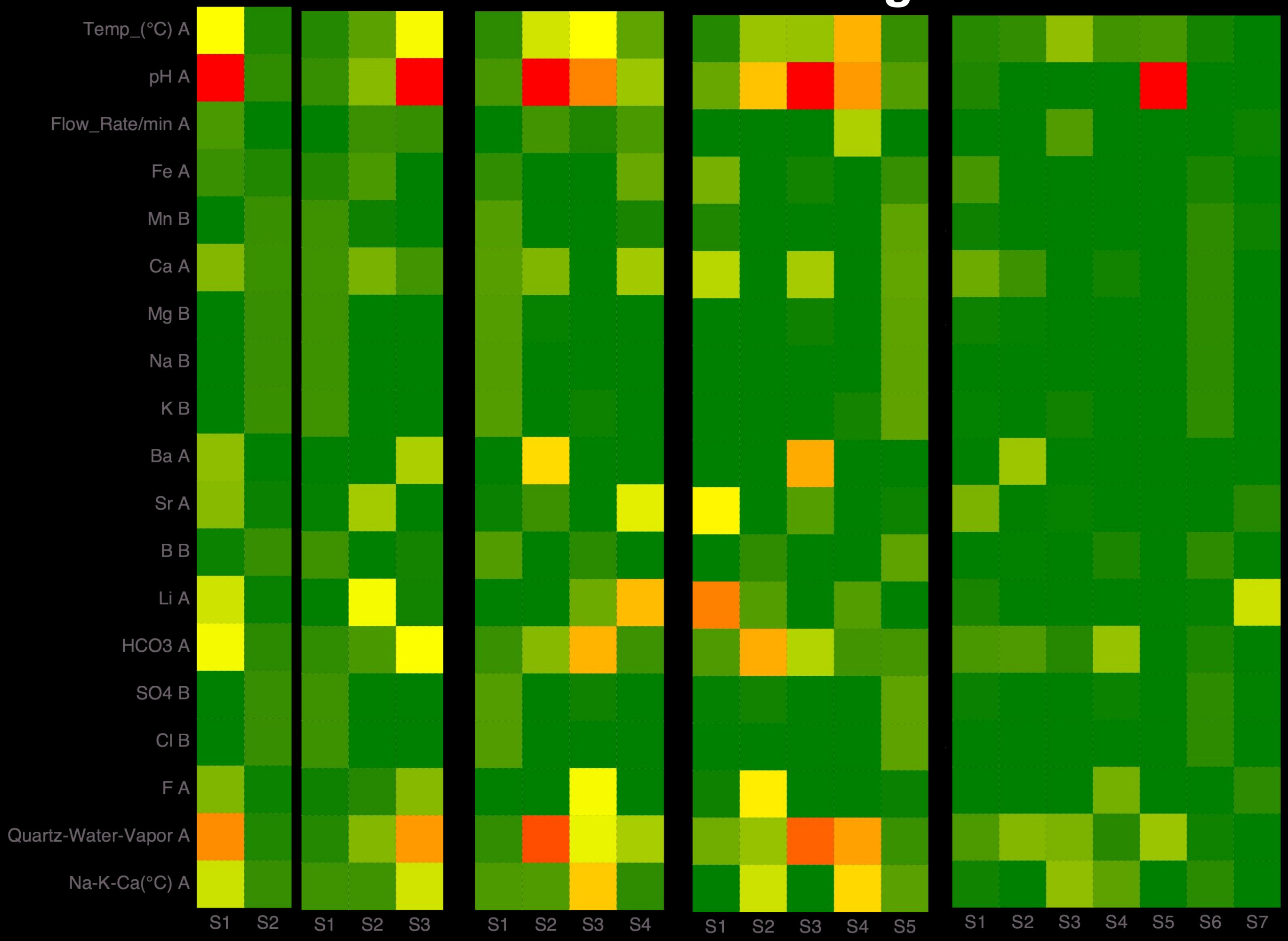
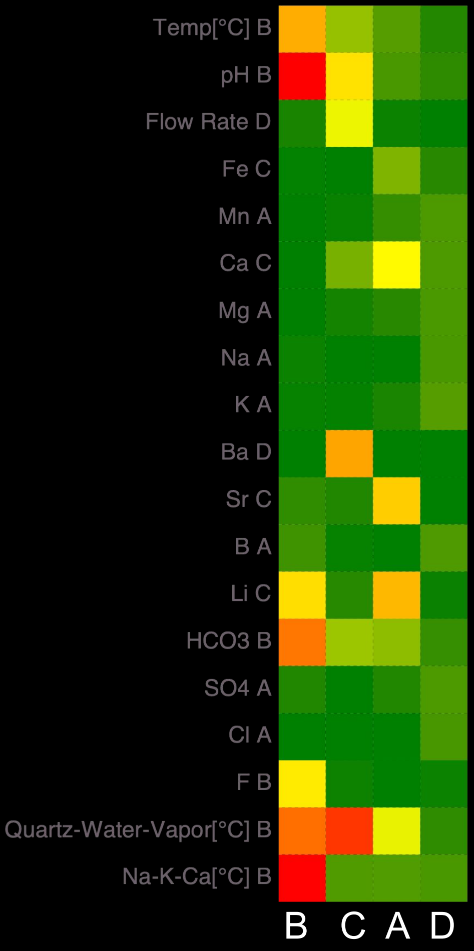
Machine Learning: NMF*k*



Hidden Geothermal Signals

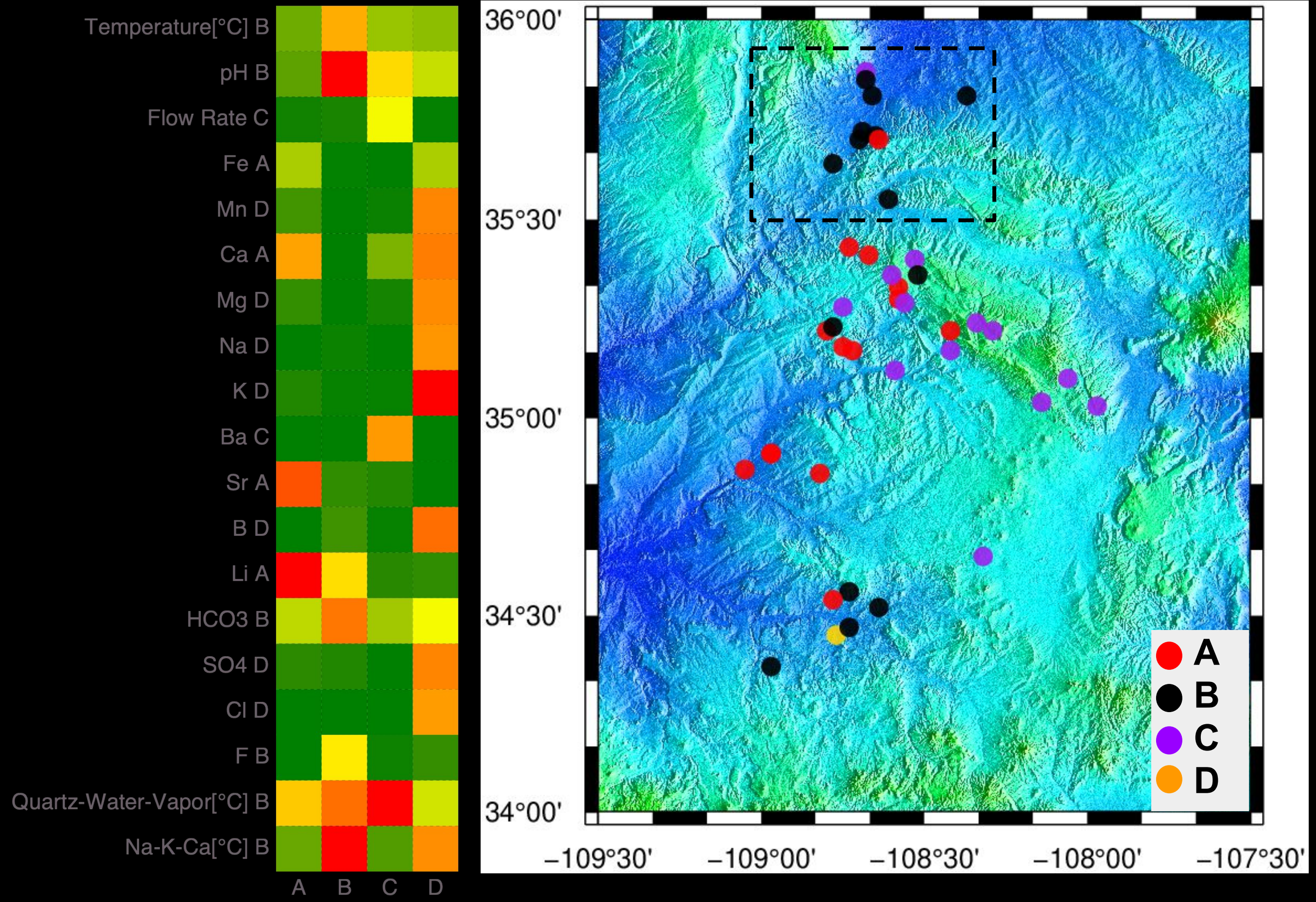


Hidden Geothermal Signals

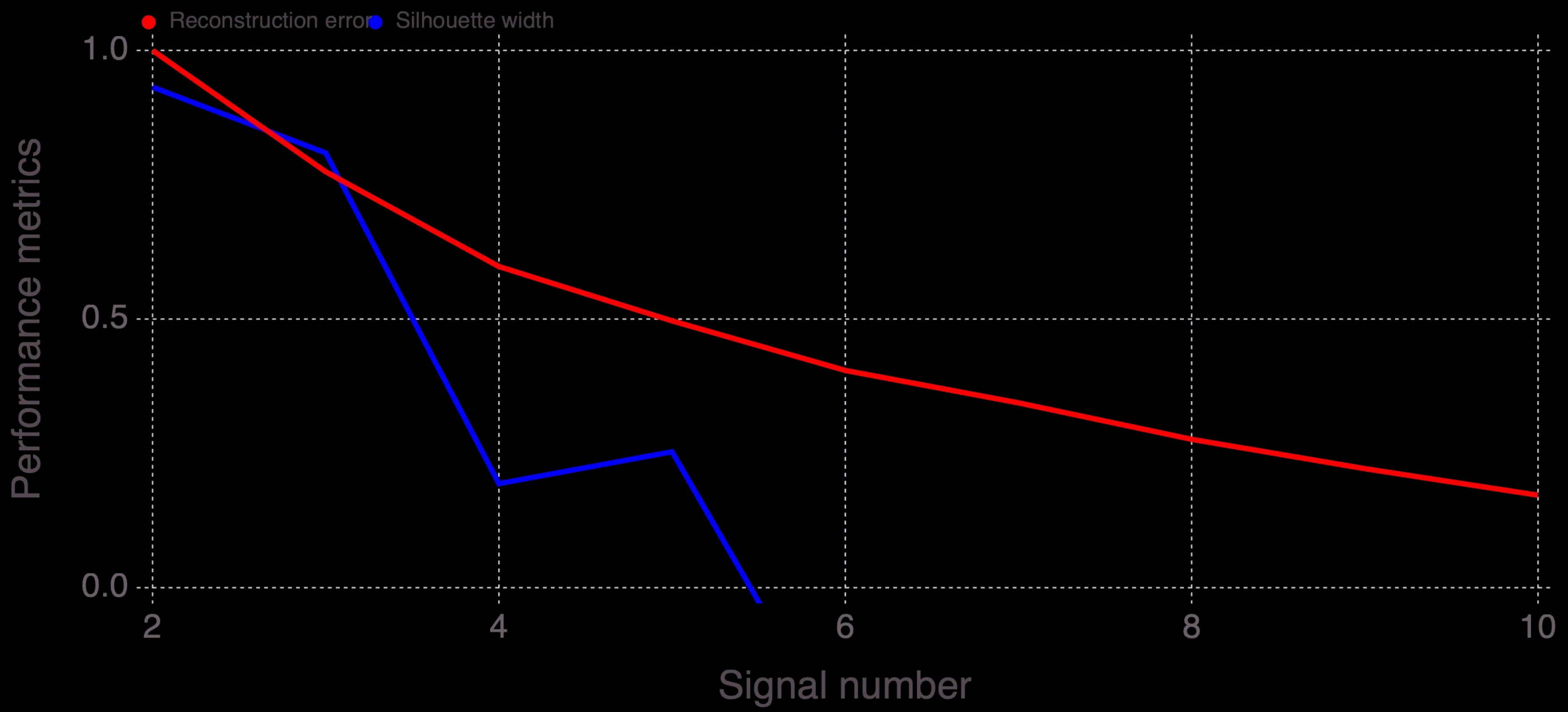


- **Signal B** represents high-temperature resources
- **Signal C** represents low-temperature resources
- Dominant attributes of Signal B are pH, Li, HCO3, and F ions, quartz and Na-K-Ca geothermometers

Preliminary Prospectivity Map



Log normalized



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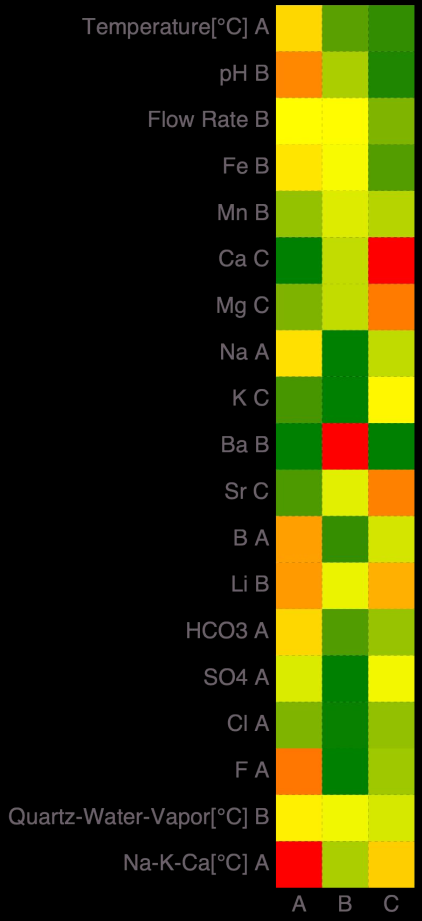

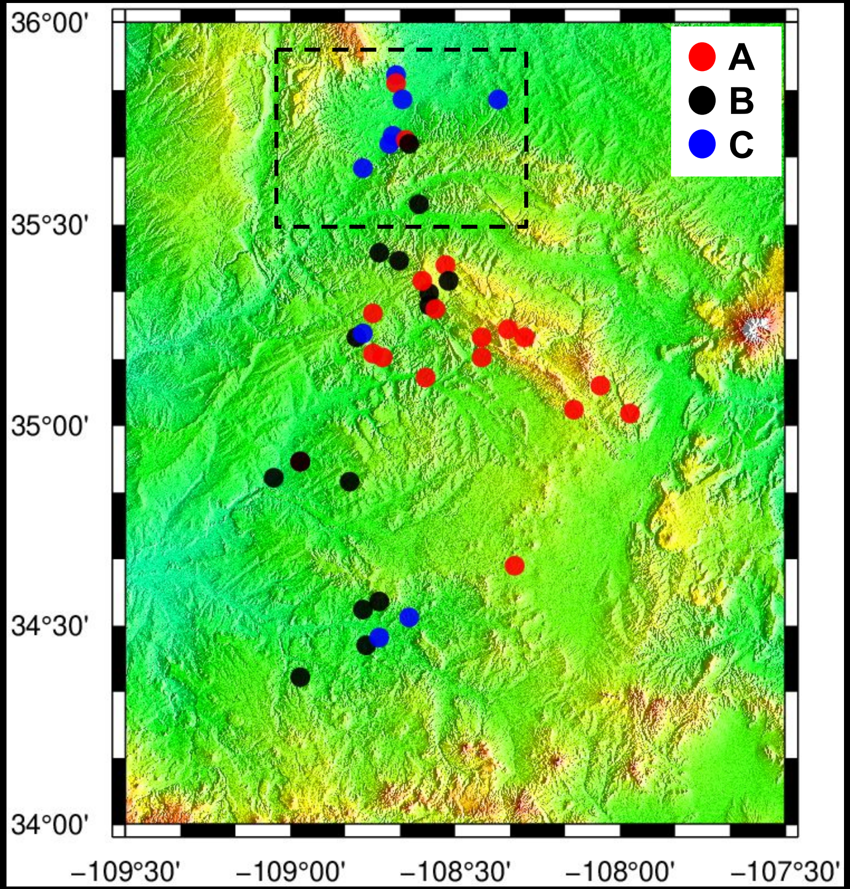

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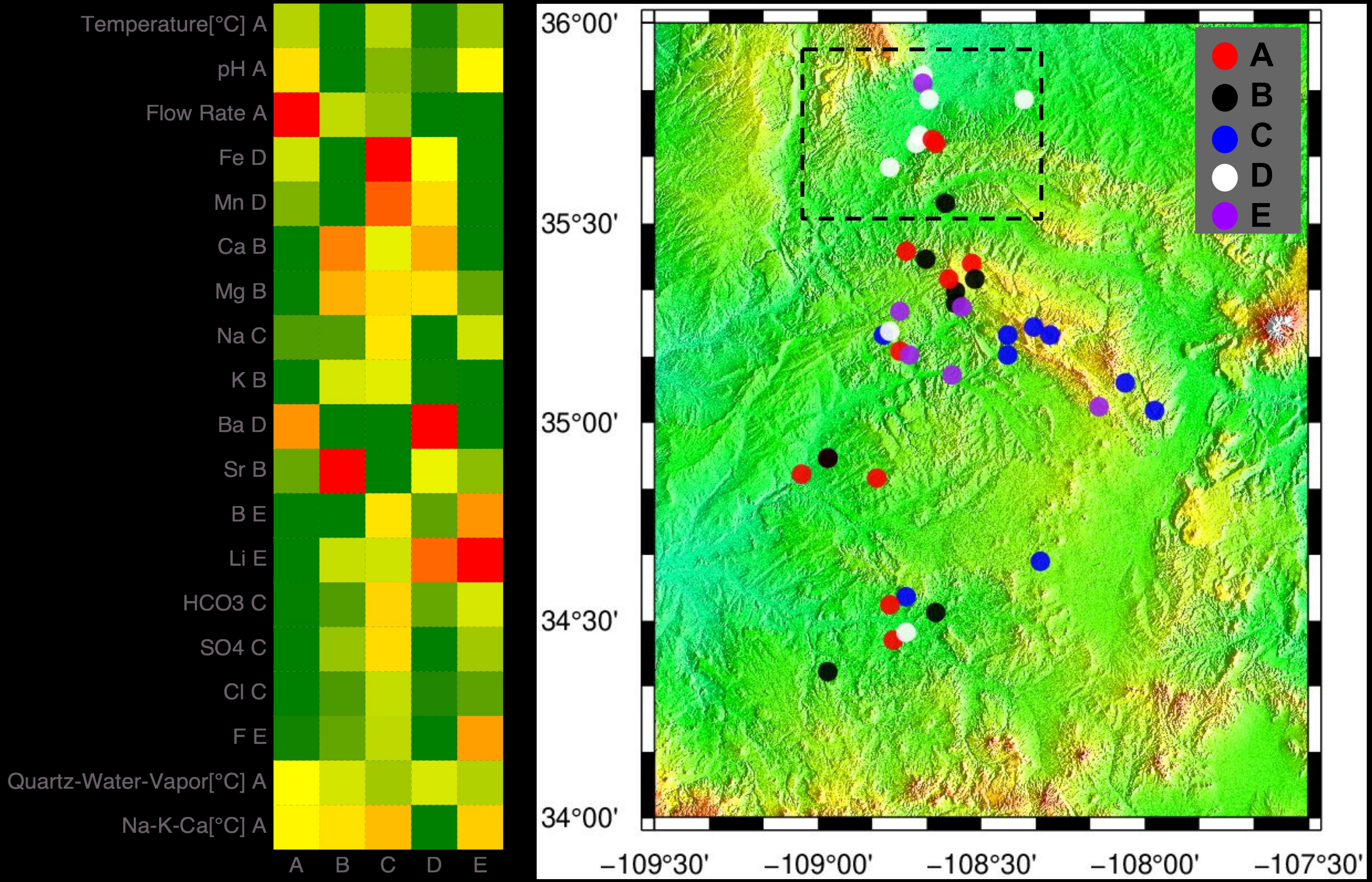
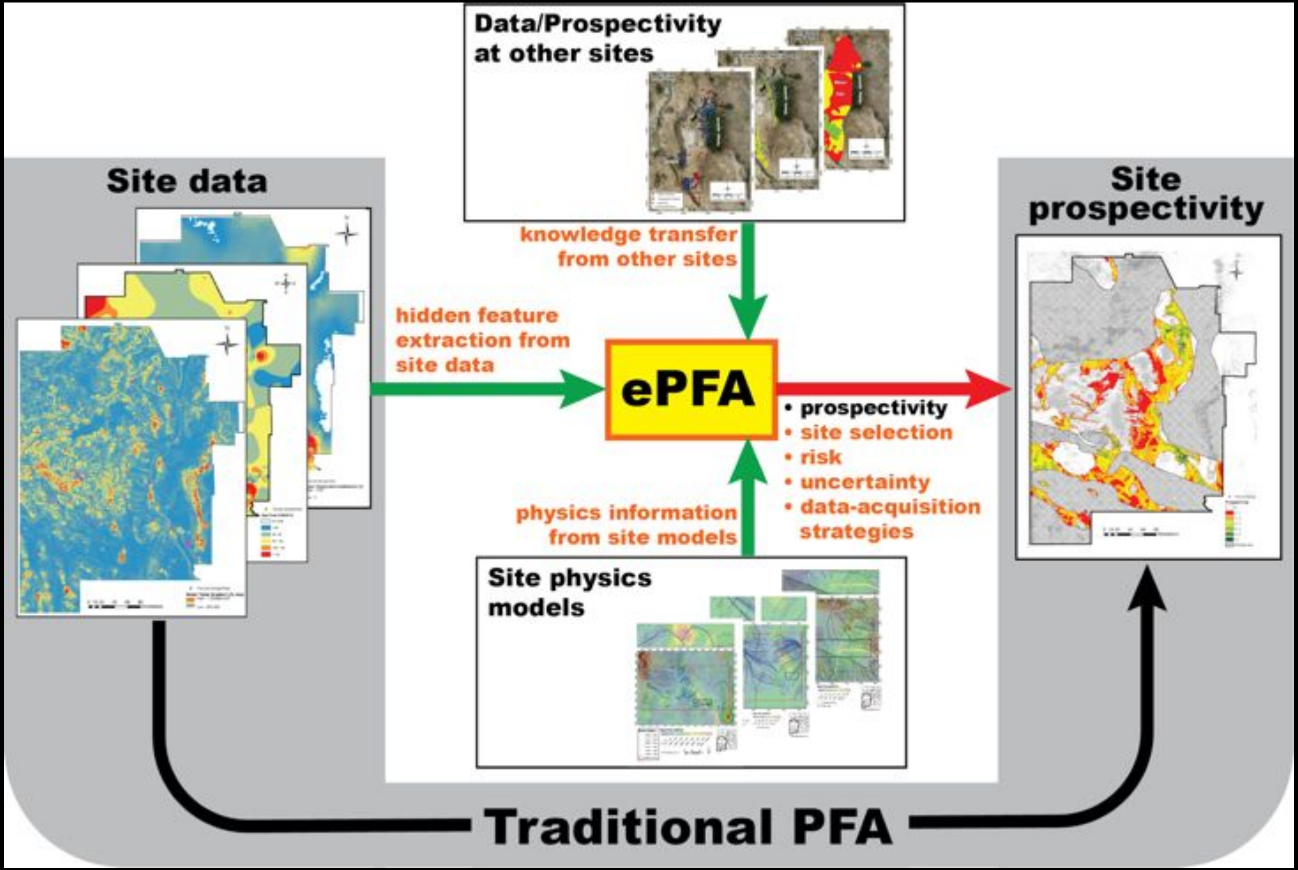


Future Work

- Develop a groundwater model to compute water flow direction, water budget, etc.
- Reserve estimation using standard porosity for sandstone, shale, and limestone
- Merge SWNM data to Tosidoh data
- Make an improved prospectivity map using the enhanced play fairway analysis method

enhanced Play Fairway Analysis: ePFA



Application of ePFA in SWNM

Thank you.

Questions?
Suggestions?